USACE Infrastructure Investments with Integration of Climate Change, Sea-Level Rise, and Other Scenarios

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Research Objective

Integrate existing methods of MCDA* with scenario analysis to a critical problem in infrastructure safety and management:

(i) Identify robust investment alternatives, and

(ii) Identify the scenarios that matter most to science and decision making

* Multiple Criteria Decision Analysis

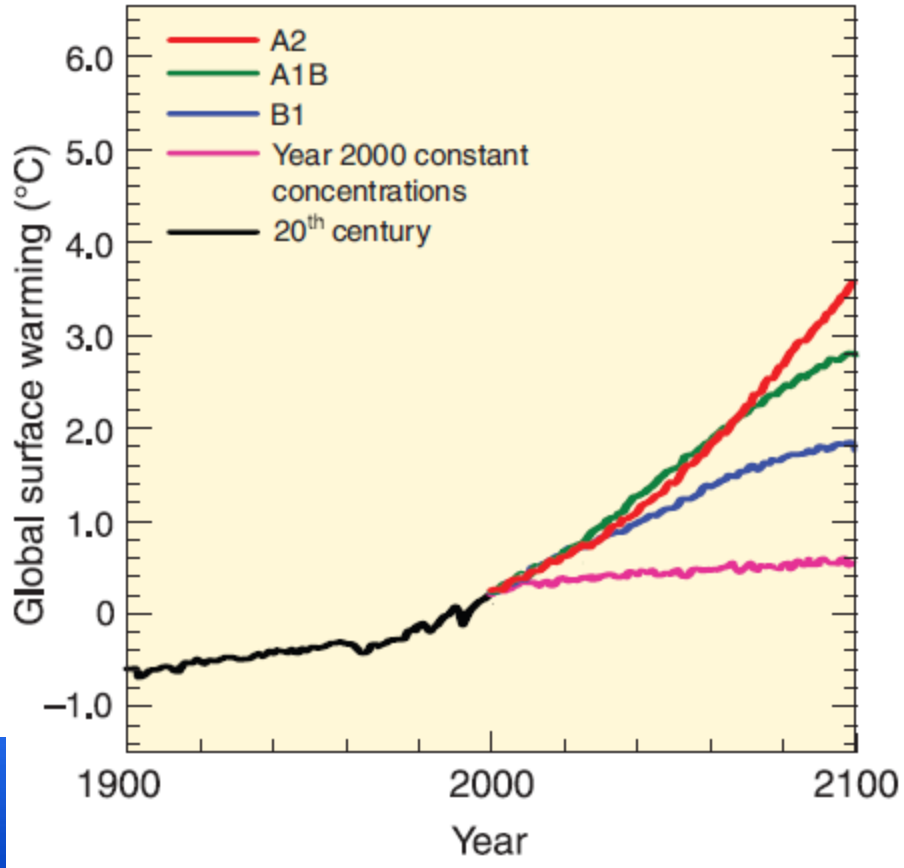
Outline

- Scenario and decision making
  - Overview of scenarios for CC
  - SA/MCDA methodology
  - Guiding questions
- Ongoing case study: Alaska baseline erosion assessment
  - Investment alternatives/communities
  - Criteria, assessments, and weights
  - Emergent conditions and scenarios
  - Expected results
- Closing/questions

Scenarios

Climate Change and Temperature Increase

The IPCC gives estimates of climate change for the variables of temperature change and sea-level rise in terms of **scenarios**. These scenarios are variables for many models.

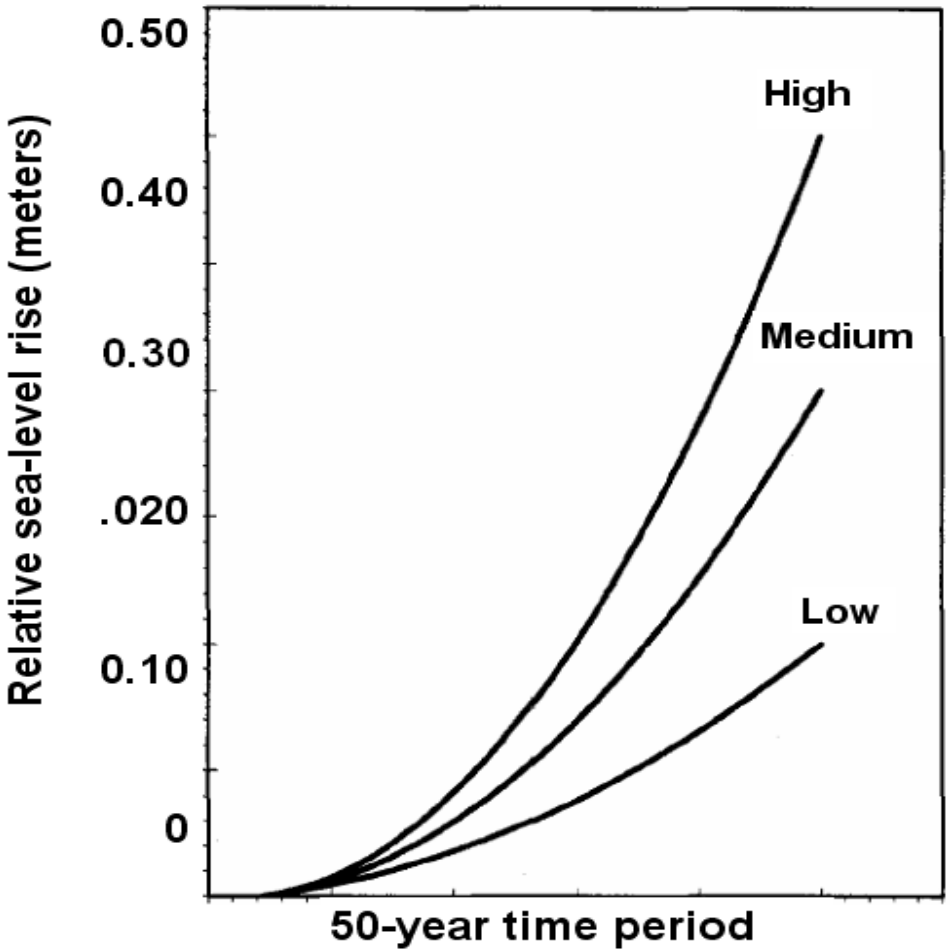


[IPCC 2007]

CLIMATE CHANGE 2007
SYNTHESIS REPORT

USACE and Sea-Level Rise

The US Army Corps of Engineers requires that "planning studies and engineering designs should consider alternatives that are developed and assessed for the entire range of possible future rates of sea-level change."



United States Army Corps of Engineers (2009a). Water Resource Policies and Authorities Incorporating Sea-Level Change Considerations in Civil Works Programs. Circular No. 1165-2-211

Scenarios and Advocacy Perspectives

Such **scenarios** are identified by modeling and analysis, but also can emerge from the advocacy positions of system owners, stakeholders, and other groups.

Approach: Portfolios of Risk Management Actions

Definition of portfolios of investments for flood and erosion control subject to climate change

Actions	Portfolios				
	X_1	X_2	X_3	X_4	X_5
a_{01} 1(a) Revetment					
a_{02} 1(b) Revetment					
a_{03} 1(c) Revetment					+
a_{04} 2(a) Seawall 1				+	
a_{05} 2(b) Seawall 1					
a_{06} 2(c) Seawall 1			+		
a_{07} 3(a) Seawall 2				+	
a_{08} 3(b) Seawall 2					+
a_{09} 3(c) Seawall 2					
a_{10} 4(a) Beach nourishment		+			
a_{11} 4(b) Beach nourishment					
a_{12} 4(c) Beach nourishment	+				
a_{13} 5(a) Dune nourishment		+			
a_{14} 5(b) Dune nourishment					
a_{15} 5(c) Dune nourishment					

[Knuuti 2002]

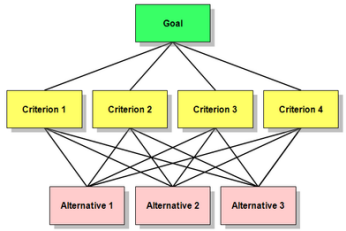
Scenario-Based MCDA Approach

Decision Making Under Uncertainty

- Uncertainty in decision making process from multiple sources
  - Model uncertainty
    - Internal uncertainty related to structuring problem, elicitation, and analysis
  - External sources of uncertainty (emergent conditions)
    - Outside control of decision maker (other than what alternative to implement)

Integrating Scenario Analysis with MCDA

- An integration of SA with multiple criteria decision analysis (MCDA) is complementary the following reasons:



  - SA can address external uncertainty in MCDA when probability-based utility methods fail
  - MCDA can quantify robustness of a decision across the scenarios
  - Influential scenarios can be filtered accordingly to their impact on decision making

- **<u>Anchor and adjusta baseline value function for each scenario</u>** [Karvetski et al. 2010a, 2010b; Ram et al. 2010; Montibeller et al. 2006; Stewart 2005; Goodwin and Wright 2001]

Literature of Methodologies Available

- Multi-criteria decision analysis (MCDA)
  - Belton and Stewart (2002); Keeney (1992); Keeney and Raiffa (1976); Clemen and Reilly (2001)
- Scenario analysis
  - Montibeller et al. (2006); Goodwin and Wright (2001); Karvetski et al. (2010a)
- Risk analysis
  - Haimes (2009); Lowrance (1976); Pate-Cornell (1996); Kaplan and Garrick (1981)
- Engineering for climate change and other emergent conditions
  - IPCC (2007); Karvetski et al. (2010b)

Approach: Criteria and Assessments

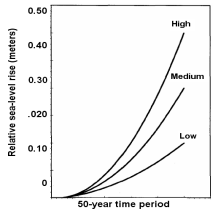
Criteria	Portfolios				
	X_{01}	X_{02}	X_{03}	X_{04}	X_{05}
z_1 Protect from coastal inundation	0.4	0.6	0.9	0.5	0.3
z_2 Protect public infrastructure systems	0.4	0.4	0.6	0.8	0.9
z_3 Protect against storm surges and flooding	0.5	0.3	0.8	0.7	0.6
z_4 Protect wetlands and environment	0.4	0.6	0.3	0.2	0.3
z_5 Protect recreational activities	0.9	0.7	0.1	0	0

Criteria	Baseline weights
z_1	0.20
z_2	0.20
z_3	0.20
z_4	0.20
z_5	0.20

Integration of Scenarios

Creation of Scenarios

Conditions	Scenarios				
	e_0	e_1	e_2	e_3	e_4
c_{01} Global sea-level rise 0.09 meters	x				
c_{02} Global sea-level rise 0.11 meters					x
c_{03} Global sea-level rise 0.17 meters		x			
c_{04} Global sea-level rise 0.33 meters			x		
c_{05} Global sea-level rise 0.49 meters				x	
c_{06} Moderate increase in coastal immigration		x			
c_{07} Significant increase in coastal immigration					x
c_{08} Moderate increase in coastal emigration					
c_{09} Significant increase in coastal emigration					
c_{10} Increased loss of native animal species' habitat				x	
c_{11} Increased loss of forest and plant life					
c_{12} Increased mortality of native animal species					
c_{13} Increase in area tourism		x			
c_{14} Decrease in area tourism					
c_{15} Increased wear and tear on public infrastructures					
c_{16} Increased wear and tear on private buildings					
c_{17} Increased in frequency of tropical storms					
c_{18} Increased in precipitation levels of tropical storms					
c_{19} Increased in wind levels of tropical storms					
c_{20} Increased vulnerability of public utilities					



Want to consider the joint effect of different conditions.

Guiding Questions

- What scenarios are most influential?
- What decision alternatives are best in a possible future scenario?
- What alternatives have opportunities in/across the future scenarios?
- What alternatives are threatened by the future scenarios?

Scenario effect on criteria

{moderate sea-level rise, moderate increase in coastal immigration, increase in area tourism}

Criteria	Scenarios			
	e_1	e_2	e_3	e_4
z_1 Protect from coastal inundation	Minor Increase	Major Increase	Major Increase	Major Increase
z_2 Protect public infrastructure systems				
z_3 Protect against storm surges and flooding				
z_4 Protect wetlands and environment			Major Increase	Minor Decrease
z_5 Protect recreational activities	Major Increase		Minor Decrease	Minor Increase

Select major/minor, increase/decrease in relevance of criteria with respect to a baseline value function

The challenge is to integrate the qualitative input in a way that theoretically consistent with MCDA (Karvetski et al. 2010).

Scenario effect on criteria (cont.)

Criteria	Scenarios			
	e_1	e_2	e_3	e_4
z_1 Protect from coastal inundation	0.22	0.34	0.33	0.35
z_2 Protect public infrastructure systems	0.16	0.17	0.15	0.17
z_3 Protect against storm surges and flooding	0.16	0.17	0.15	0.17
z_4 Protect wetlands and environment	0.16	0.17	0.33	0.07
z_5 Protect recreational activities	0.31	0.17	0.06	0.24

Each new set of weights represents the perspective of a future scenario.

Approach: Desired Information (cont)

{moderate sea-level rise, moderate increase in coastal immigration, increase in area tourism}

Scenarios	Portfolios				
	X_{01}	X_{02}	X_{03}	X_{04}	X_{05}
e_0	2	2	1	4	5
e_1	1	2	3	4	5
e_2	3	2	1	4	5
e_3	4	2	1	3	5
e_4	3	2	1	4	5

Portfolios that are ranked highest

Case Study: Alaska Baseline Erosion Assessment

Alaska Baseline Erosion Assessment

"Serious erosion is threatening the viability of the community, or, in some cases, significant resources are being expended to minimize those threats. The erosion issues in these communities warrant immediate and substantial Federal, State, or other intervention."

Kivalina, Alaska

- *Alaska Baseline Erosion Assessment,* Alaska District, US Army Corps of Engineers, March 2009

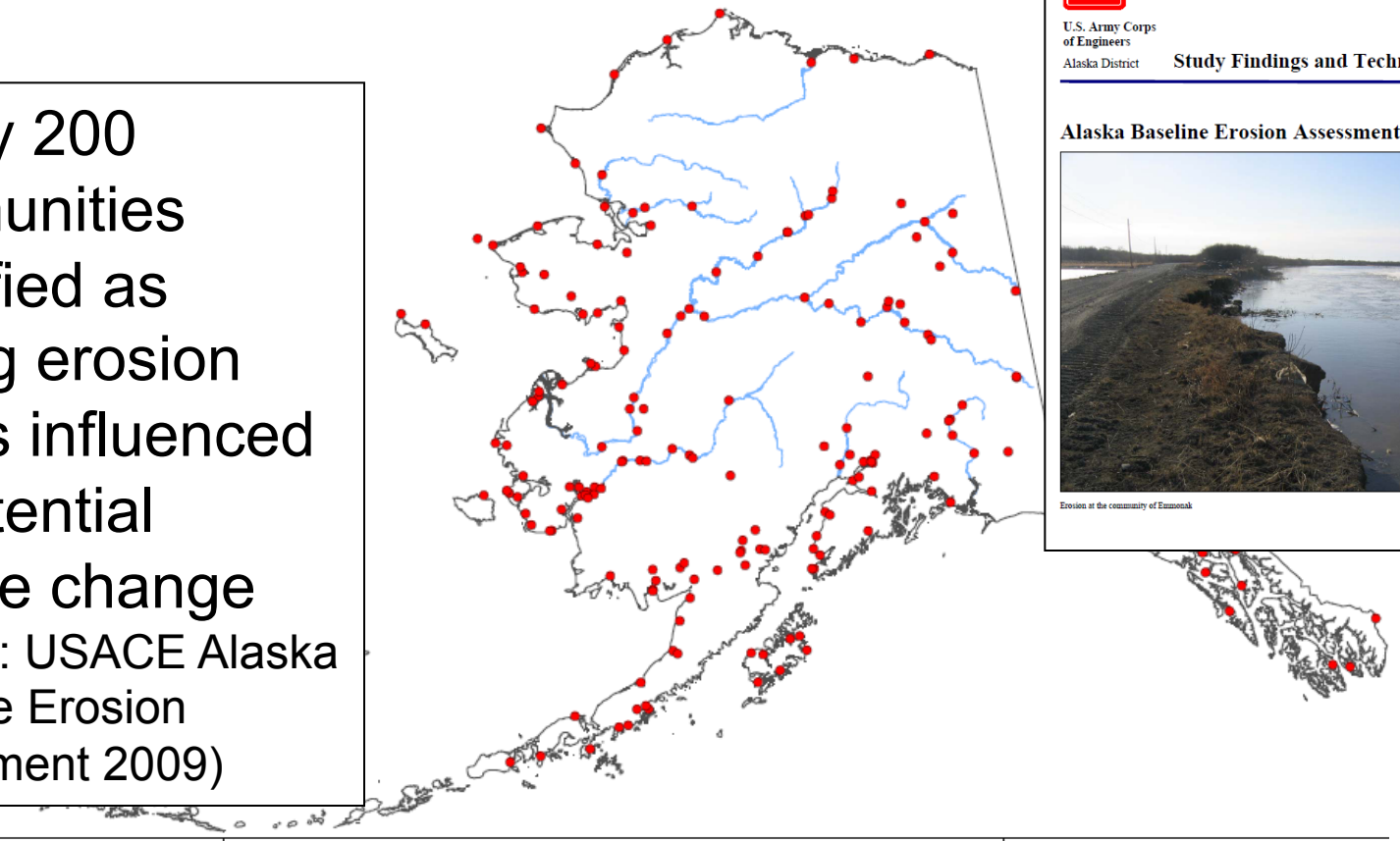
Background: Alaska Baseline Erosion Assessment

- Building on Baseline Erosion Assessment (USACE, 2009)
  - Communities (alternatives)
  - Criteria
  - Weighting system

- Integrating scenarios of climate change and other emergent conditions into Alaska Baseline Erosion Assessment

Background: Alaska Baseline Erosion Assessment (cont.)

Nearly 200 communities identified as having erosion issues influenced by potential climate change (Source: USACE Alaska Baseline Erosion Assessment 2009)



Background: Priority Action Communities—Projects

- Barrow, AK
- Chefornak, AK
- Deering, AK
- Emmonak, AK
- Huslia, AK
- Kivalina, AK
- Shishmaref, AK
- Others

Unalakleet, AK. Sagging gabion wall

- *Alaska Baseline Erosion Assessment,* Alaska District, US Army Corps of Engineers, March 2009

Background: Alaska Baseline Erosion Assessment-Criteria

- Selection of criteria relevance

Criteria	Relevance
Critical infrastructure	***
Human health and safety	***
Subsistence and shoreline use being limited	**
Community setting/geographic location	*
Housing and population	*
Housing in parallel	**
Environmental hazard	***
Cultural importance	*
Commercial/non-residential	**

Key	
***	High relevance
**	Medium relevance
*	Low relevance
	No relevance

- *Alaska Baseline Erosion Assessment,* Alaska District, US Army Corps of Engineers, March 2009

Emergent conditions

- Storm surges
- Increased/decreased population
- Increased/decreased flooding
- Increased/decreased tourism
- Permafrost melt
- Loss of species
- Loss of habitat
- Wild fires

- Increase in soil salinity
- Decrease in soil salinity
- Increase in storm frequency
- Decrease in storm frequency
- Sea level rise - high
- Sea level rise - low
- Increase in sea ice
- Decrease in sea ice

Expected Results

Project Ranks

Projects	Baseline	Sea level rise > 1m	Decrease in sea ice
Barrow, AK	7	12	9
Chefornak, AK	10	10	8
Chevak, AK	4	3	4
Clarks Point, AK	10	8	11
Cordova, AK	4	3	4
Deering, AK	13	16	15
Dillingham, AK	22	22	22
Emmonak, AK	7	6	7
Golovin, AK	10	8	11

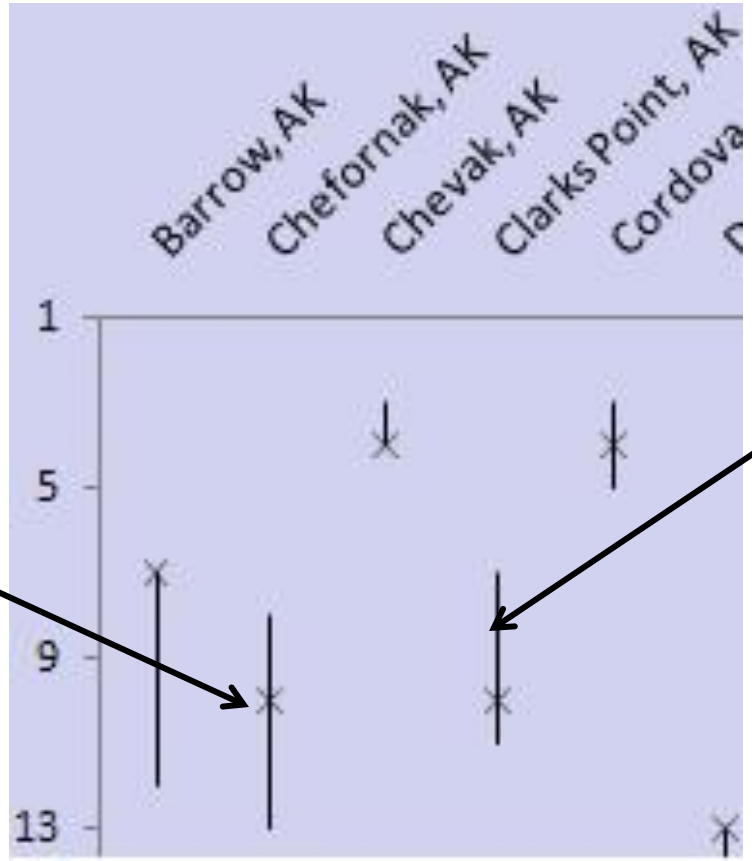
The rank of each project varies across scenarios

Bank erosion along the Kotlik shoreline, 2007

Project Ranks

Projects	Baseline	Sea level rise > 1m	Decrease in sea ice	Storm surge + Incr. erosion	Sea level rise < 1m	Increase in sea ice	Incr. Flooding	Decr. erosion	Highest Rank	Lowest Rank	Median Rank
Barrow, AK	7	12	9	11	7	8	12	9	**7**	**12**	**9**
Chefornak, AK	10	10	8	12	9	10	13	10	**8**	**13**	**10**
Chevak, AK	4	3	4	3	4	3	3	4	**3**	**4**	**4**
Clarks Point, AK	10	8	11	7	9	10	7	10	**7**	**11**	**10**
Cordova, AK	4	3	4	5	4	5	5	5	**3**	**5**	**5**
Deering, AK	13	16	15	13	15	14	14	15	**13**	**16**	**15**
Dillingham, AK	22	22	22	22	22	22	21	21	**21**	**22**	**22**
Emmonak, AK	7	6	7	9	7	8	9	8	**6**	**9**	**8**
Golovin, AK	10	8	11	7	9	10	7	10	**7**	**11**	**10**
Huslia, AK	15	14	14	16	13	16	16	16	**13**	**16**	**16**
Kivalina, AK	1	1	1	1	1	2	1	2	**1**	**2**	**1**
Kotlik, AK	2	2	2	2	2	1	2	1	**1**	**2**	**2**
Lime Village, AK	20	19	20	19	20	19	19	19	**19**	**20**	**19**
McGrath, AK	4	3	4	3	4	5	3	7	**3**	**7**	**4**
Newtok, AK	3	7	3	9	3	4	10	3	**3**	**10**	**4**
Nunapitchuk, AK	19	18	19	18	19	18	18	18	**18**	**19**	**18**
Port Heiden, AK	16	17	16	17	16	17	17	17	**16**	**17**	**17**
Saint Michael, AK	13	13	13	13	12	13	14	13	**12**	**14**	**13**
Selawik, AK	20	19	20	19	20	19	19	19	**19**	**20**	**19**
Shaktoolik, AK	17	15	17	15	17	15	11	14	**11**	**17**	**15**
Shishmaref, AK	7	11	9	6	13	7	6	6	**6**	**13**	**7**
Unalakleet, AK	17	21	17	21	17	21	22	22	**17**	**22**	**21**

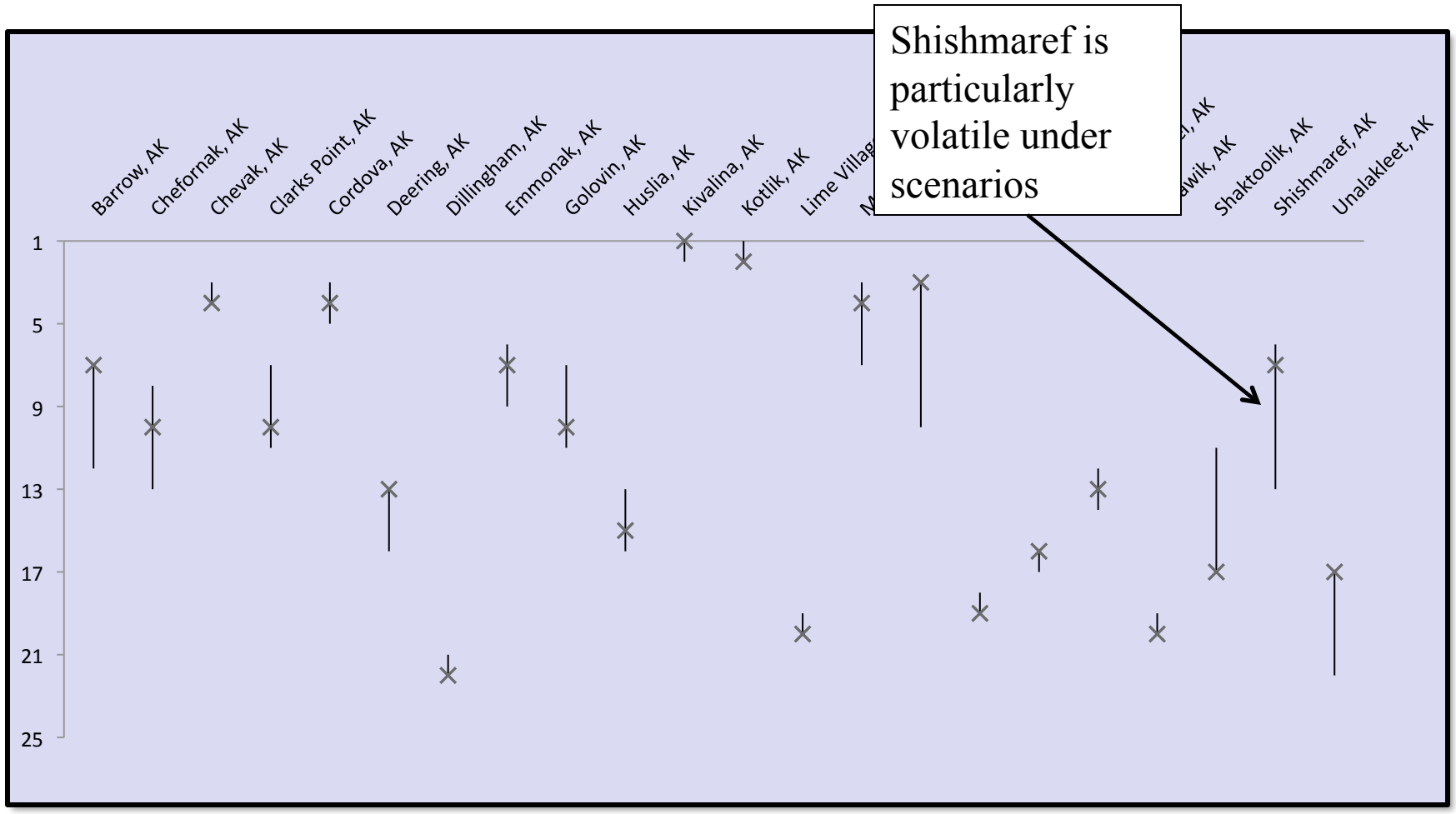
Influence of the Scenarios on the Prioritization



"x" represents the baseline rank

Height of the bar indicates increased sensitivity relative to the baseline

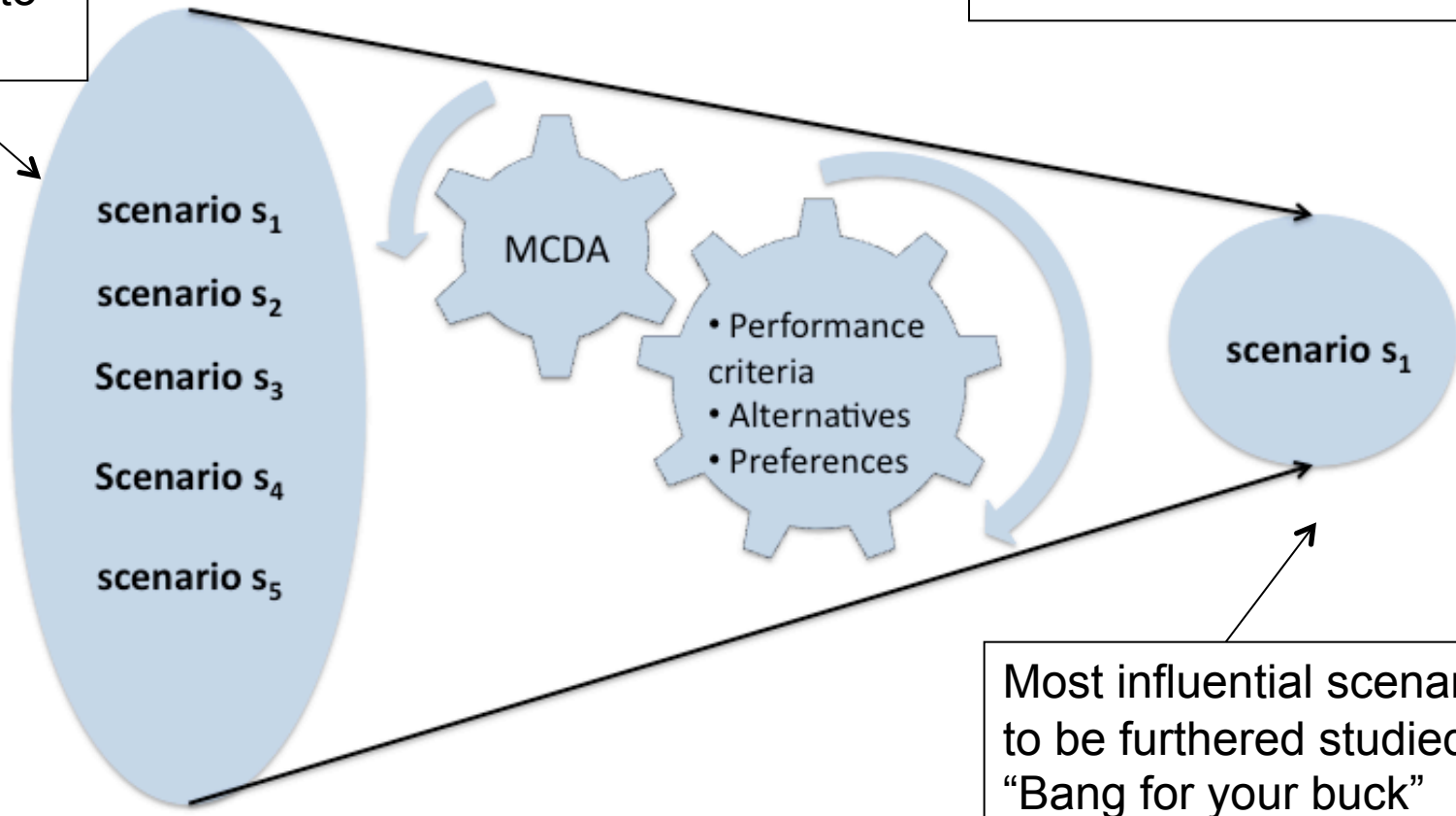
Influence of the Scenarios on the Prioritization



Scenario Prioritization

We seek to identify opportunities and threats across the scenarios and identify influential scenarios

Large set of scenarios to be filtered



Most influential scenarios to be furthered studied – "Bang for your buck"

Scenario Prioritization – Most Impactful

Scenario Scores

Highest SSE

Scenario	SSE
Sea level rise > 1m	16812
Increased Flooding	10880
Decrease in sea ice	3360

Cordova, AK

- Scenarios with the highest sum of squared error (SSEs)

Scenario Prioritization – Least Impactful

Scenario Scores

Lowest SSE

Scenario	SSE
Increase in sea ice	543
Decreased erosion	706
Sea level rise < 1m	960

Nunapitchuk, AK

- Scenarios with the lowest sum of squared error (SSEs)

Summary

- Determine robustness of community prioritization
- Determine where to guide future engineering investigations
  - Based on the most influential scenarios
- Climate change must be considered among social, demographic, technological, economic, regulatory, and other emergent conditions

Kotlik, AK

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